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Operation UPSHOT-KNOTHOLE

NEVADA PROVING GROUNDS

March - June 1953

scale 8

Project 6.2

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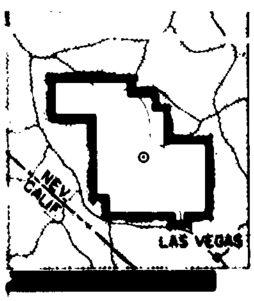

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ABSTRACT

Results obtained from participation in previous atomic tests proved conclusively that nuclear detonations of 3 KT and higher could be detected and displayed on the indicators of standard X-band radar bombing systems and Ku-band radar systems. Participation in Operation UPSHOT-KNOTHOLE provided an opportunity to test new techniques believed applicable to an Indirect Bomb Damage Assessment (IBDA) system as well as to investigate certain phenomena associated with a nuclear detonation which might affect the interpretation of the radar display.

Three B-29 type aircraft participated in Project 6.2 and were instrumented as follows: 1) Fast scan Ku-band radar set AN/APS-48(XA-1) and instrumentation to investigate the electromagnetic wave emanating from a nuclear detonation, as applied to the determination of height-of-burst; 2) Standard scan Ku-band radar set AN/APS-43(XA-1) and Airborne Moving Target Indicator (AMTI) equipment, radar set AN/APS-27 (XA-5); 3) radar set AN/APS-23 modified in accordance with High Information Content Study (HICS) procedures, which results in radar pictures containing more detailed information than can normally be obtained from unmodified radar sets.

Four Mark III Bhangmeters were tested during the operation. Two Bhangmeters were installed in two of the B-29 aircraft for all shots except Shot 9 when one was installed in each of two B-29's and two were installed in the drop aircraft, B-50 #7169. The yield measuring portion of the instruments gave results which appear to be withi the measurement accuracy for Bhangmeters. The time-of-fall mechanism did not perform satisfactorily due to mechanical malfunctioning of the clock mechanism.

The Nevada Proving Ground portion of this project investigated the refraction of a radar beam passing near a fireball, endeavored to obtain fundamental data concerning various phenomena associated with a nuclear detonation by observing the direct radar returns, and ascertained if a correlation exists between any of the various characteristics of the returns and the yield of the detonations. Details of this part of Project 6.2 may be found in Appendix A of this report. The refraction of the radar beam was too small to be resolved. Radar reflection from the fireball was not observed. However, on all experiments large fluctuations of radar signal amplitude were present, which is interpreted as being due to interference effects between signals that had traveled different paths.

It is concluded that to obtain IBDA parameters, a fast scan type radar set is desirable but not necessary; that the AMTI equipment tested is too susceptible to interference to be considered usable in an IBDA system; that some of the HICS procedures and modifications are desirable for inclusion in an IBDA system but none are considered necessary to obtain the IBDA parameters; that it is not practical to use the electromagnetic wave emanating from a nuclear detonation to determine its height-of-burst above ground.

FOREWORD

This report is one of the reports presenting the results of the 78 projects participating in the Military Effects Tests Program of Operation UPSHOT-KNOTHOLE, which included 11 test detonations. For readers interested in other pertinent test information, reference is made to WT-782, Summary Report of the Technical Director, Military Effects Program. This summary report includes the following information of possible general interest.

a. An over-all description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the 11 shots.

b. Compilation and correlation of all project results on the basic measurements of blast and shock, thermal radiation, and nuclear radiation.

c. Compilation and correlation of the various project results on weapons effects.

d. A summary of each project, including objectives and results.

e. A complete listing of all reports covering the Military Effects Tests Program.

PREFACE

The purpose of this report is to present the results of tests of techniques believed applicable to Indirect Bomb Damage Assessment systems and also report the results of investigations of certain phenomena associated with a nuclear detonation which might affect the interpretation of the radar display.

The writer wishes to acknowledge the cooperation and assistance afforded Project 6.2 by the program director and his staff. This assistance was especially appreciated by project personnel stationed at the Nevada Proving Ground who found themselves faced with numerous and unexpected difficulties which were overcome through the assistance of the program director. The writer also wishes to acknowledge the assistance and work performed by all personnel directly associated with Project 6.2 and the assistance rendered by; Air Force Special Weapons Center, and particularly the 4925th Test Group (Atomic); Sandia Corporation's movie and still film processing laboratories; Radar personnel from Air Force Armament Center; and the SAC aircraft crew from Barksdale Air Force Base.

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CHAPTER 1

OBJECTIVE

1.1 GENERAL

Since participation in Operation BUSTER-JANGLE, new techniques had been developed which were believed applicable to an Indirect Bomb Damage Assessment (IBDA) system. Operation UPSHOT-KNOTHOLE provided an opportunity to test these techniques and determine if they were of sufficient importance, to include in a proposed IBDA systems, meeting the requirements of Headquarters, USAF.

As a result of previous tests and the proposed use of the observed radar returns, questions were raised regarding the refraction of a radar beam when in close proximity to a fireball and if the observed radar return could be correlated with the yield of the nuclear detonations. These two points were investigated by installations at the Nevada Proving Ground (NPG).

1.1.1 Radar Set AN/APS-48 (XA-1)

This radar set operates in the Ku-band and has a "looking" rate of 8.6 "looks" per second as compared to a standard radar rate of 1.4 "looks" per second. It was believed that the increased number of frames containing the radar return would insure usable IBDA data.

1.1.2 Radar Set AN/APS-27 (XA-5)

This radar set is an Airborne Moving Target Indicator (AMTI) and consists of radar set AN/APS-23 and additional modifying boxes. Since the radar returns from a nuclear detonation are associated with the advancing shock front, at its point of intersection with the ground, it was thought that an AMTI system might present the returns more clearly than a standard radar set. If two indicators were attached to the system, one to present the AMTI returns and another to present regular radar returns, an overlay or combination of the resulting pictures might provide more accurate measurements of the IBDA parameters.

1.1.3 High Information Content Study System (HICS)

This system utilizes radar set AN/APS-23 modified and operated in accordance with the procedures resulting from the HICS study. The radar picture resulting from these procedures was to have more detailed information than is normally obtained from standard radar sets operated in the usual manner, and would therefore provide more accurate measurements of the IBDA parameters.

1.1.4 Electromagnetic Wave Experiment

During the course of an IBDA study contract, the contractor, Vitro Corporation of America, proposed that the height-of-burst of a nuclear detonation might be determined by utilizing the electromagnetic wave which emanates from a nuclear detonation. This could be accomplished in an aircraft by measuring the time difference between the receipt of the direct wave and the wave reflected from the ground. Information regarding the characteristics of the electromagnetic wave as received on the ground is available from several sources, however, the characteristics of the electromagnetic wave as received in an aircraft had never been determined. The instrumentation employed was to provide the desired information.

1.1.5 Mark III Bhangmeters

These Bhangmeters consisted of a yield measuring device, based on the light-time curve, and a clock mechanism to record time-of-fall, which can be converted to the height-of-burst of a weapon dropped from an aircraft.

1.1.6 Nevada Proving Ground Experiments

These are covered in detail in Appendix A of this report.

CHAPTER 2

BACKGROUND AND THEORY

2.1 BACKGROUND

Headquarters USAF has placed upon Headquarters Air Research and Development Command a requirement to develop an all-weather IBDA system. By the use of this system it will be possible to evaluate the effect of nuclear weapons upon enemy installations. The IBDA parameters which are collected by the strike aircraft or accompanying aircraft will be used to determine the amount of damage inflicted upon the target by relating the value of these parameters to overpressure or by other suitable procedures. This correlation is not a part of the activity of the agency developing the system to which the tests described herein pertain. Advantages of such a system are obvious. Not only is operational planning of future strikes expedited, but also the requirement for immediate post-strike reconnaissance will be eliminated.

2.1.1 Previous Tests

Analysis of plan position indicator photographs taken during Operations CROSSROADS, SANDSTONE, GREENHOUSE, BUSTER-JANGLE, TUMBLER-SNAPPER, and IVY indicate that the observed radar return results from detonations of 3 KT and higher, when detonated under the conditions which prevailed during these tests. The returns from detonations in the Pacific Proving Grounds (PPG) area are much easier to obtain since radar gain controls can be set higher due to the lack of continuous ground painting. Furthermore, most of the detonations at the PPG are of higher yields than those detonated at the NPG, which results in a better radar return. However, it is believed that yields of 15 KT and higher can be detected over areas such as the NPG with moderate care in the setting of the various radar controls.

Since it has been proven 8,9/ that radar techniques can be used to obtain the ground-zero parameter needed for IBDA, and radar is an all-weather device, an IBDA system based on the AN/APQ-24 and K-series bombing systems has been proposed to fulfill the requirements

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of Headquarters, USAF. Since this IBDA system has been proposed and placed in a development stage, new radar techniques had become available which were believed applicable to the proposed IBDA system or to a new and better IBDA system and UPSHOT-KNOTHOLE provided an opportunity to determine the feasibility of the proposed techniques.

2.2 THEORY

The cause of the observed radar return obtained from a nuclear detonation has been discussed since the phenomena were first observed during CROSSROADS. Many theories have been advanced, however as a result of their study contract, Vitro Corpor tion of America has recently stated that most of the observed results are consistant with a theory that states that the radar return is due to the breaking up of the earth or wate by the shock wave. The shock wave forces earth or water into the air, thereby increasing the effective reflection coefficient by increasing the aspect angle and by increasing the area available for reflections. Further detailed explanations may be found in Vitro report No. KLX-1659 3/.

The fireball cloud shadow, first observed during BUSTER-JANGLE 8/, is a useful aid in determining gross errors in height-of-burst and yield. The fireball cloud associated with a nuclear detonation absorbs radar energy for a varying time, dependent upon the yield of the detonation. Therefore, a shadow is cast upon the ground over an area representing the fireball cloud and this area appears on the radar as an area of no ground return, hence the name "fireball cloud shadow".

The tests conducted during UPSHOT-KNOTHOLE indicate that there is no "early bright spot return" from the nuclear detonation itself. Therefore, it is concluded that previously observed phenomena of this type 8/ must be due to the shock wave's first intersection with the ground, directly under the air burst.

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CHAPTER 3

INSTRUMENTATION

3.1 GENERAL

The instrumentation employed by Project 6.2 was briefly discussed in Chapter 1 of this report. The radar sets and Bhangmeter are described in detail in the respective documents listed in the bibliography. The instrumentation employed by the airborne electromagnetic wave experiment consisted of a loop antenna to receive the direct and reflected electromagnetic wave. The signals were then presented on a DuMont type 294A oscillograph. A Polaroid Land camera and a Warrick Model F continuously moving film camera were used to record the signals presented on the oscillograph. Detailed information regarding this experiment may be found in Vitro report, KLX-1659 3/.

The radar data obtained by radar sets AN/APS-48(XA-1), AN/APS-43 (XA-1) and AN/APS-27(XA-5) were displayed on a plan position indicator and also as an "A" type presentation on DuMont type 294A oscillographs. The radar set plan position indicators were photographed with type O-15 Recording Cameras and the "A" presentations by Bell and Howell high speed motion picture cameras and Warrick Model F continuously moving film cameras. The instrumentation used and the modifications required in the radar sets is covered in BUSTER-JANGLE report WT-344 8/.

The High Information Content Study system consists of a basic radar set AN/APS-23 modified by the addition of an "electronic gray wedge" which eliminates the bright center that is characteristic of radar displays; an "anti-halation" circuit in the PPI indicator to remove the bright spot in the center of the indicator tube; specially focused O-15 recording camera with matched film magazines; a trimetrigon installation of K-17 aerial cameras triggered by the radar set; and improved mirrors in the O-15 recording camera optical system. In addition, a second indicator was employed which was photographed by an O-9 camera giving a 1:1 photographic recording of the radar presentation.

The instrumentation employed by the NPG portion of the project is covered in Appendix A of this report, and in somewhat greater detail in Vitro report KLX-1658 12/.

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CHAPTER 4

OPERATIONS

4.1 AIRCRAFT

The three B-29 aircraft assigned to this project operated from Kirtland Air Force Base, Albuquerque, New Mexico, throughout the operation. At the NPG the aircraft were positioned in space at what was considered optimum positions for the techniques under test. In general, the positioning was not critical and the aircraft were some 8 to 10 miles slant range from ground zero at the time of detonation. The aircraft were under the operational control of the 4925th Test Group (Atomic) and followed the operational plan and instructions published by that organization.

4.2 EQUIPMENT, AIRBORNE

In general, the instrumentation employed was calibrated and adjusted prior to each shot. The procedures employed were not unique in any respect and are therefore not considered of sufficient importance to include in this report.

4.3 EQUIPMENT, NEVADA PROVING GROUND

This is covered in Appendix A of this report and in greater detail in Vitro report KLX-1658 12/.

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CHAPTER 5

RESULTS AND DISCUSSION

5.1 GENERAL

The airborne portion of this project was performed to gather qualitative information from the techniques employed as they might be applied to an IBDA system. The results obtained were pictures of radar Plan Position Indicators showing ground zero, the radar return received from a nuclear detonation and the cloud shadow phenomena which has been observed during previous tests. Sample pictures of the results obtained are not included in this report. Report reproduction techniques degrade radar pictures to the extent that it becomes difficult for the reader to distinguish differences that are apparent when viewing glossy prints or the original film. Furthermore, sample pictures of nuclear detonations as viewed on X-band and Ku-band radar sets amy be seen in GREENHOUSE, BUSTER-JANGLE and TUMBLER-SNAPPER reports, which are listed in the bibliography. Therefore, only verbal results are presented for the techniques tested.

The NPG portion of this project is covered in Appendix A of this report.

5.1.1 Radar Set AN/APS-48 (XA-1)

This radar set was used in 10 of the 11 shots. No data were obtained from two of the shots because of equipment malfunction, and from one shot because of the film being fogged by radioactivity. Of the remaining seven shots, radar returns were observed from three shots. When radar returns were obtained, the returns were visible for many more frames than obtained from a standard radar, however, due to the power and antenna limitations of this radar set, the overall presentation was very poor and not as detailed as that obtained by standard radar sets. Therefore, the technique of fast scan radar is concluded to be desirable but certainly this particular radar set is not applicable to IBDA.

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5.1.2 Radar Set AN/APS-27(XA-5)

Unfortunately this radar set was installed in an aircraft which failed to participate in three shots because of engine failures. The aircraft was not scheduled to participate in two shots, and the radar set failed on one shot. Of the remaining five shots, radar returns were observed from three shots. During the operation it was noted that this radar set was extremely susceptible to interference from other radar sets in the general area, which makes its application to IBDA highly questionable. The AMTI technique appears to be applicable to IBDA to detect the radar return associated with the advancing shock front. However, an AMTI technique must be developed that eliminates, or reduces appreciably, the jamming vulnerability which this radar set now has.

5.1.3 Radar Set AN/APS-43(XA-1)

This radar set was installed in the same aircraft as radar set AN/APS-27(XA-5), therefore it was not used on five of the 11 shots. Of the remaining six shots, radar returns were obtained from four shots. The results obtained from this radar were far superior in quality to those obtained by radar set AN/APS-48(XA-1). This was expected, since this radar set has higher power output and a larger antenna which will provide a picture which contains greater detail and has better definition.

5.1.4 High Information Content Study System(HICS)

The HICS system was operated on eight of the 11 shots. Of the eight shots, radar returns were obtained from six shots, however several of the returns are of doubtful value for IBDA purposes. Radar returns from three of the shots were considered satisfactory for IBDA purposes. In general, the techniques employed in the HICS system should be used when they are available in standard radars. No marked difference in the quality of the radar returns was noticed to the extent that the techniques should be considered a necessary part of an IBDA system.

5.1.5 Electromagnetic Wave Experiment

This experiment was performed by Vitro Corporation and is reported in great detail in their report KLX-1659 3/. In general, some information was obtained concerning the nature of the electromagnetic signals received by aircraft from nuclear detonations. There may be a correlation between yield and the amplitude of the electromagnetic signal but there was not enough data to confirm this belief. The electromagnetic signals were much more complicated than originally anticipated. As a result of this, the direct and reflected signals were difficult to distinguish. A considerable amount of judgment was required to decide which part of the electromagnetic signal was the direct signal and which part was the reflected signal.

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This situation makes this method of burst-height measurement subject to substantial error. Assuming the interpretation of the electromagnetic signals to be correct, this method of measuring burst height is subject to very serious errors for burst heights on the order of 500 ft or less. For such small burst heights, the value calculated by this method may be as much as five times too large. For burst heights on the order of several thousand feet, errors up to 50 per cent may be expected.

5.1.6 Mark III Bhangmeters

The yield measuring portion of the Mark III Bhangmeters performed quite satisfactorily, as evidenced by the results tabulated in Table 5.1. The time-of-fall mechanism failed to provide satisfactory results, which is attributed to poor mechanical design of the clock mechanism. Project aircraft were not scheduled to participate in Shot 6, therefore no reference to Shot 6 appears in Table 5.1. It will be noticed in Table 5.1 that on Shot 11 two of the Bhangmeters received results that were not usable because of a poorly defined minimum. This was the result of adding protective filters to the photoheads, which caused the light curve minimum to fall in the base line making it impossible to determine the minimum point on the curve.

It is generally known that the formula used to relate yield to time-to-first-minimum is one which is derived empirically. The yields given in Table 5.1 are based upon the formula

$$Y = 0.085\, t^2 \tag{5.1}$$

where Y = yield in kilotons
t = time to first minimum in milliseconds

Formula 5.1 is recommended by the Mark III Bhangmeter manufacturer, Edgerton, Germeshausen & Grier, as the one best suited for use in the NPG area, considering the size of the nuclear devices detonated.

Attention is invited to the results obtained on Shot 3 by all Bhangmeters. It is only fair to state that there is not a clearly defined minimum for shots of this small size. However, if the person interpreting the results uses good judgment, fairly realistic results can be obtained.

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TABLE 5.1 - Mark III Bhangmeter Results

SHOT	RAD. CHEM. YIELD, KT	BHANGMETER YIELD, KT			
		SERIAL "1	SERIAL "2	SERIAL "3	SERIAL "4
1	16.2	NOT INSTALLED	NO RESULTS	NOT INSTALLED	16.6
2	24.5	NOT INSTALLED	27.5	AIRCRAFT ABORT	AIRCRAFT ABORT
3	0.20	0.34	0.53	0.53	0.34
4	11.0	10.3	TRACE NOT READABLE	AIRCRAFT NOT SCHEDULED	AIRCRAFT NOT SCHEDULED
5	23	26	26	AIRCRAFT ABORT	AIRCRAFT ABORT
7	43.4	37.4	37.4	AIRCRAFT ABORT	AIRCRAFT ABORT
8	27	27.5	32.3	27.5	29
9	26	27.5	24.6	26	26
10	14.9	16.6	17.9	14.4	19.1
11	60.8	RESULTS NOT USABLE POOR MINIMUM	62	RESULTS NOT USABLE POOR MINIMUM	62

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CHAPTER 6

CONCLUSIONS

6.1 RADAR TECHNIQUES

The radar techniques tested, i.e., fast scan radar, HICS system, and AMTI principle, are all desirable and could probably be used in an IBDA system to assist in obtaining the required ground zero parameter. However, none of the techniques, individually or collectively, could be considered important enough to warrant the development of a special system for IBDA utilizing these techniques. In the future, when standard bombing systems are available which include these techniques as part of the bombing system, it is the opinion of the writer that the ground zero parameter will be obtained with greater ease and probably more accuracy than it can now be obtained with the AN/APQ-24 and K-series bombing systems.

6.2 ELECTROMAGNETIC WAVE EXPERIMENT

The use of the electromagnetic wave is not considered a practical method for measuring the height-of-burst of nuclear weapons. It is possible that this method might be developed into a useful method in the future. However, such a device would require a considerable amount of further development as well as refinement of the techniques used on this experiment. Even then, owing to the complexity of the electromagnetic signals, it would not be possible to decide on the feasibility of this method until a considerable amount of information had been obtained about the characteristics of electromagnetic signals emitted by nuclear detonations.

6.3 MARK III BHANGMETERS

It can be concluded that the technique employed for measuring yield is satisfactory. However, the time-of-fall mechanism must be redesigned for reliable operation.

6.4 NEVADA PROVING GROUND EXPERIMENTS

As a result of the refraction experiments performed at NPG it was concluded that the refraction of a radar beam, which is in close proximity to the fireball cloud, was too small to be measured in the presence of other large scale effects. Based on these results, it can be said that refraction is negligible and can therefore be ignored in IBDA data reduction procedures.

Results of the experiment designed to detect radar returns from the fireball indicate that there is no radar return from the fireball. The phenomena observed by airborne radar, the annular return and the fireball cloud shadow, were not detected in this experiment. Therefore, it can be concluded that any "bright-spot" returns observed on radar PPI's are not a result of reflections from the fireball but are probably caused by the shock wave when it first hits the ground. It can be further concluded that the annular ring normally observed by airborne radar sets is a return from "radar reflectors" which are on the ground. Since the antenna depression angle of this ground operated radar was very small, it appears that the height of these "radar reflectors" is too small to cause a radar return, however, the depth is sufficient to provide a return to radar sets which are airborne and have an antenna depression angle of approximately 45 degrees.

CHAPTER 7

RECOMMENDATIONS

7.1 RADAR TECHNIQUES

None of the techniques tested contribute sufficiently to an IBDA system to warrant the development of a special system for IBDA. Therefore, it is recommended that the techniques be used as applicable when they become available as part of standard bombing radar systems. It is further recommended that other new techniques, applicable to IBDA, be evaluated in future tests.

7.2 ELECTROMAGNETIC WAVE EXPERIMENT

It is recommended that no further effort be expended on the use of the electromagnetic wave to determine height-of-burst.

7.3 NEVADA PROVING GROUND EXPERIMENTS

It is recommended that the results obtained by the Project 6.2 ground experiments at NPG be considered conclusive and no further effort be expended on this type investigation.

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APPENDIX A

OPERATION UPSHOT-KNOTHOLE

Project 6.2

NEVADA PROVING GROUNDS EXPERIMENTS

by

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ABSTRACT

The objectives of Project 6.2 participation in Operation UPSHOT-KNOTHOLE at the Nevada Proving Grounds, were to investigate the refraction of electromagnetic radiation passing near the fireball, to obtain fundamental data concerning the various phenomena associated with a nuclear detonation by observation of the direct radar returns, and to ascertain if a correlation exists between any of the various characteristics of the returns and the yields of the detonations.

To accomplish these objectives two experimental systems were set up. Basically, the instrumentation for the refraction experiment consisted of a radar transmitter with its antenna aimed immediately past the fireball at an array of radar receivers in direct line of sight with the radar transmitter and the fireball. The time history experiment was instrumented with a radar set AN/APS-42 and a DuMont 294 oscilloscope on which the returns were displayed and photographed, pulse by pulse, with a high-speed camera.

The refraction of the radar beam was too small to be resolved. Radar reflection from the fireball was not observed. The annular ring and the cloud shadow were not detected. However, on all experiments large fluctuations of signal amplitude were present. The region [illegible] signals appeared to expand outwardly from ground zero.

ACKNOWLEDGMENTS

The successful performance of this project in the face of the numerous difficulties was due in large measure to the cooperation and guidance afforded us by the program director and his staff.

Recognition is due to Mr. Keeran of the Naval Electronics Laboratory (NEL) for assistance in collecting additional data with NEL equipment and for submitting films to our purposes.

APPENDIX A

NEVADA PROVING GROUNDS EXPERIMENTS

A.1 OBJECTIVE

A.1.1 General

The purpose of this portion of Project 6.2, was to observe refraction effects of radar waves in the vicinity of an atomic detonation, and to observe direct radar returns from the fireball of the detonation. Two different types of experiments were made during Operation UPSHOT-KNOTHOLE for this purpose.

A.1.1.1 Refraction Experiment

The refraction experiment was designed to determine if refraction occurs, and to what extent, when electromagnetic radiation from a radar transmitter passes near an atomic detonation. Previous reduction of radar data has been made with the assumption that electromagnetic radiation is propagated rectilinearly in the vicinity of the fireball. The occurrence of refraction would require that some correction factor be introduced.

A.1.1.2 Time History Experiment

In the time history experiment, radar returns from the fireball area were observed. This experiment had a dual purpose:

a. To determine if the direct radar returns would provide any fundamental data concerning the burst phenomena.

b. To determine if any correlation exists between the characteristics of the radar returns and the yield of the nuclear detonation.

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A.2 BACKGROUND AND THEORY

A.2.1 General Background

During Operation CROSSROADS in 1946 an experiment was conducted, as a matter of scientific interest, to determine the effects of a nuclear detonation on the performance of radar systems. For the first time radar returns reflected from the vicinity of ground zero were observed.

In 1950, Headquarters, USAF, requested Wright Air Development Center (WADC), Wright-Patterson Air Force Base, Ohio, to devise an Indirect Bomb Damage Assessment (IBDA) system. This system would be capable of measuring the three parameters, ground zero, height of burst, and yield, which are required to assess indirectly the damage caused by a nuclear detonation. Any aircraft in the strike cell including the drop aircraft, must be able to obtain the data necessary to determine the desired parameters.

The Aircraft Radiation Laboratory (ARL) of WADC proposed that a radar system, used as the sensing device, would provide a basis for an all-weather technique. A preliminary system was then formulated to determine height of burst and ground zero of a nuclear detonation from a sequence of photographs of the radar returns from the detonation as seen on a Plan Position Indicator (PPI) radar scope.

During operations GREENHOUSE, BUSTER-JANGLE, and TUMBLER-SNAPPER, the instrumentation was improved and some quantitative data were obtained.

A.2.2 Refraction Experiment

In reducing the radar data, all electromagnetic radiation was assumed to travel in straight lines. Since some rays emitted by the radar antenna pass near the fireball during a measurement, such rays may suffer appreciable refraction. If a substantial amount of refraction does occur, a method must be devised to make allowance for it in the data reduction process. The refraction experiment described in this appendix is an attempt to supply the required information.

A.2.3 Time History Experiment

While direct radar returns apparently had been obtained from nuclear detonations, more complete data on direct returns was desired. In particular, it was desired to study the radar returns for a number of test shots to determine if they would provide any fundamental information concerning the detonation. It was of particular interest to determine if the amplitude and duration of the radar returns could be correlated to the yield of the detonation. The time history experiment was designed to provide this information.

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A.3 INSTRUMENTATION

A.3.1 Refraction Experiment

A.3.1.1 Fundamental Layout

Instrumentation for the refraction experiment consisted of a radar transmitter with its antenna aimed immediately past the fireball at an array of radar receivers in direct line of sight with the radar transmitter and the fireball. (See Fig. A.1.) The changes of the transmitter antenna radiation pattern were observed by noting the variations of signal intensity at the line of radar receivers. The antenna radiation pattern was measured immediately prior to the burst and the recorded signals at the receivers permit it to be determined at any time during and after the burst. The change in position of the pattern axis, compared to its pre-burst position, is a measure of the amount of refraction occurring.

A.3.1.2 Mixer and Delay Amplifier Unit

The radar pulses detected at the line of receivers were all displayed on an oscilloscope simultaneously. To accomplish this, the signal received at any particular station was fed into a mixing circuit and combined with the signals received at the other receiver stations. To separate and distinguish the various pulses, a delay of approximately 10 microseconds was introduced at each station so that the radar pulses would appear sufficiently far apart on the oscilloscope trace so that they could be individually measured.

Video amplifiers were incorporated at each station to compensate for the attenuation caused by the long coaxial lines between receiver stations. The entire process of mixing, delaying, and amplifying was repeated at each receiver station and, ultimately, the signals were applied to the input of a DuMont type 294 oscilloscope. This oscilloscope has excellent response characteristics and a very high accelerating potential which allows the photographing of fast transients. (See Fig. A.2.)

A.3.1.3 Radar Transmitter Antenna and Radiation Pattern

The radar transmitter utilized a 60-in. parabolic reflector antenna. This antenna has a 1.7° beam width between the half-power points at the X-band radar frequency of 9375 megacycles, the operating frequency of radar set AN/APS-42.

A minimum of five points were required to delineate the broad over-all outline of the radiation pattern of the antenna. For this reason, the angular separations between the receiver stations as measured from the transmitter were set at 0.425° each. Since maximum deviation of 3° was anticipated, 16 receiver stations were used in the receiver line. This allowed for two receiver stations on either side of the expected end points of the detector line as a margin of safety.

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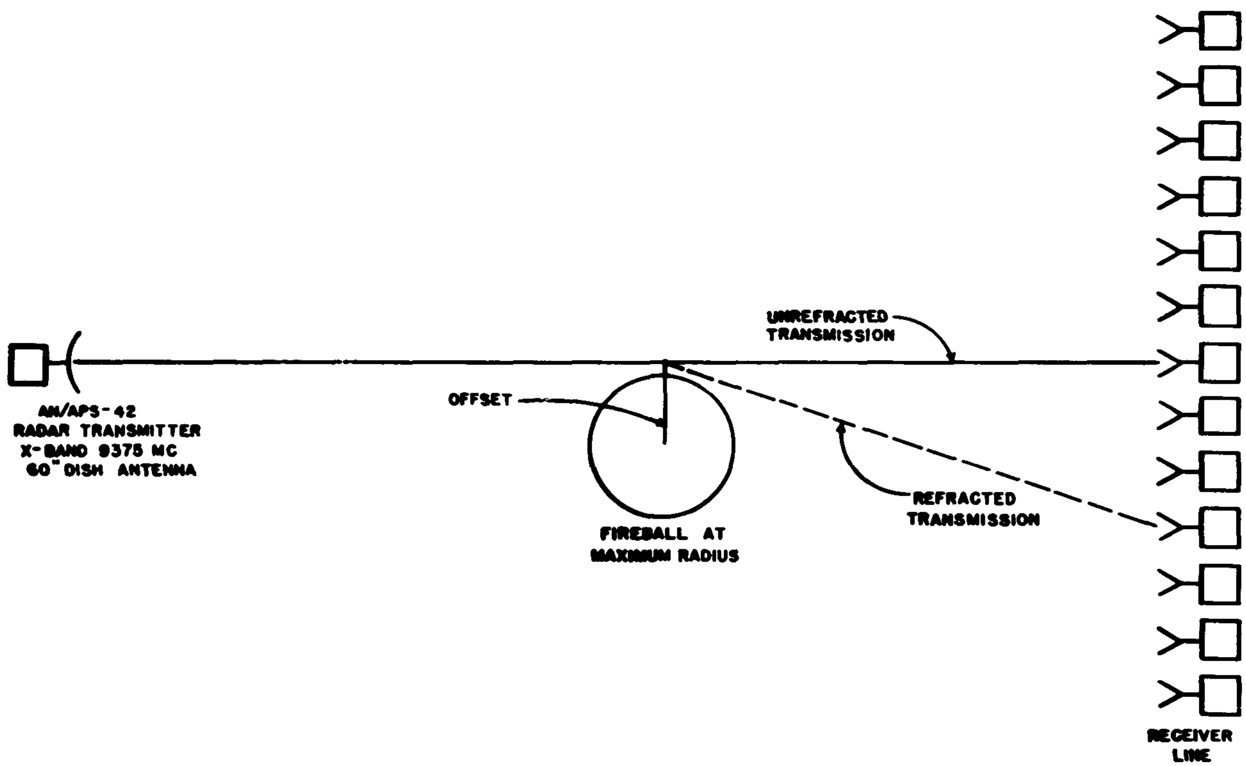

Fig. A.1 Schematic Layout for Refraction Experiment Showing Relative Position of Radar Transmitter, Line of Receivers, and Fireball

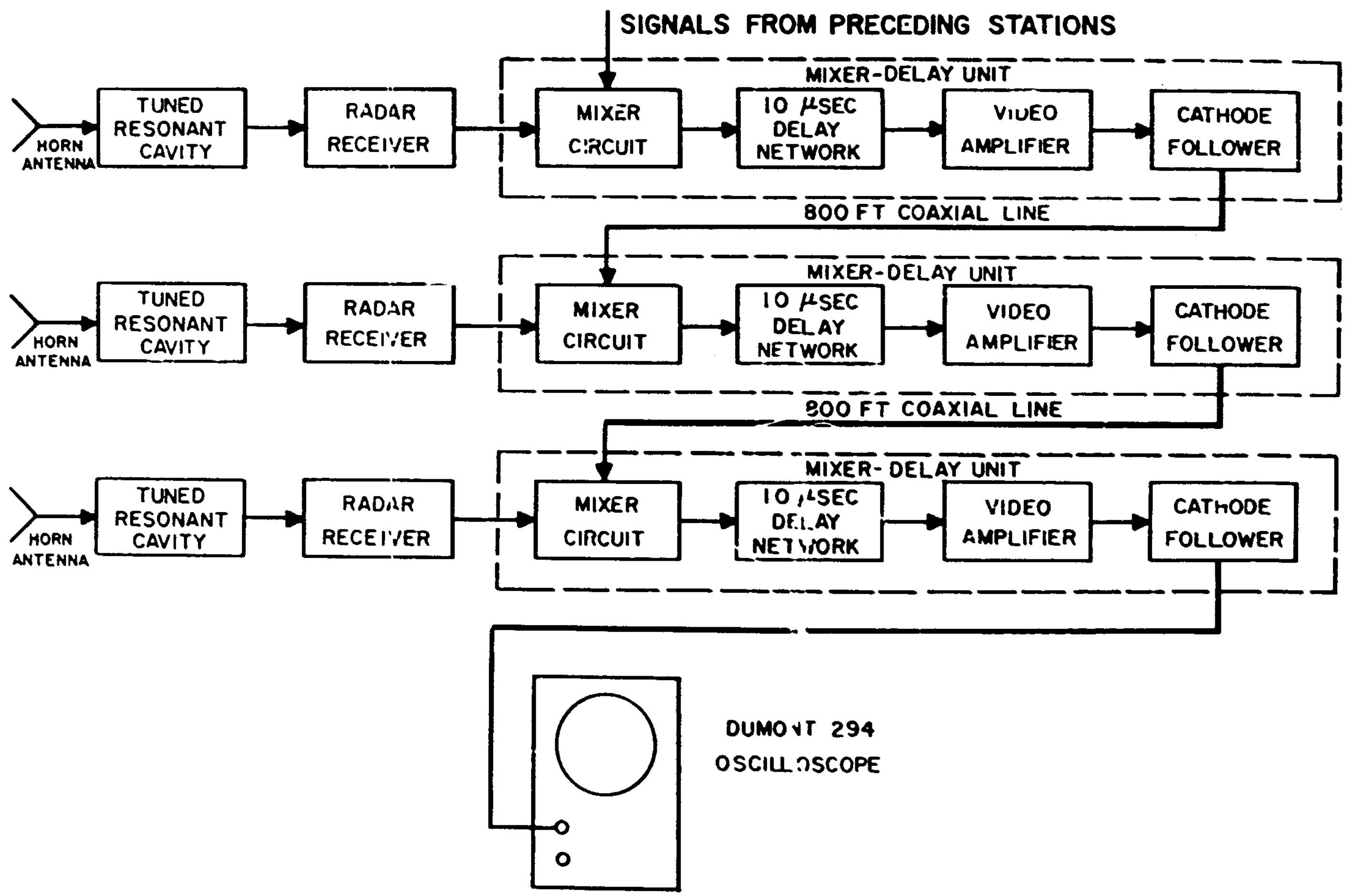

Fig. A.2 Block Diagram of Receiver Line and Oscilloscope

Because the distance between the receiver stations was a function of the distance from the radar transmitter to the receivers, the separation between the receivers varied from shot to shot from 500 to 800 ft. With 16 stations in the receiver line and an 800 ft separation between receivers, the receiver line extended 2.3 miles from end to end. (See Fig. A.3.)

A typical, although idealized, antenna radiation pattern as detected at the receiver array is shown in Fig. A.4. In this figure, the transmitter antenna was centered on receiver station No. 5 and examples are shown for both the situations with and without the presence of refraction.

A.3.1.4 Synchronization Network

To maintain the received signal pulses at the correct relative position on the oscilloscope trace, an external signal was applied to the oscilloscope to initiate the sweep. This sweep signal was synchronized with the pulses from the radar transmitter so that an oscilloscope trace was initiated just prior to the arrival of the signals at the first receiver. The synchronization loop was provided by installing a radar receiver at the original transmitter site and a second radar transmitter off to one side of the receiver line. (See Fig. A.5.)

The synchronizing transmitter, radar set AN/APS-10, was placed far to one side of the receiver line to minimize the possibility of the burst blanking out the synchronizing signal. The synchronizing signal was sent simultaneously by coaxial line to the oscilloscope and by air to the synchronizing receiver.

To prevent other radar signals from triggering the AN/APS-42 transmitter, both the synchronizing transmitter and the synchronizing receiver were equipped with 60-in. parabolic reflector antenna having a narrow beam width 1.7° and a gain of 32 db each. This resulted in a very strong signal at the synchronizing receiver, allowing the receiver sensitivity to be reduced and thereby decreasing the possibility of triggering on spurious signals.

A delay circuit was added between the oscilloscope and the synchronizing transmitter to allow sufficient time for the synchronizing pulse to travel to the synchronizing receiver, trigger the AN/APS-42 radar transmitter, and still allow adequate time for this newly transmitted pulse to arrive at the receiver line. The delay time, of the order of 200 microseconds, was provided by a TS-592 pulse generator modified to provide the extra long delay required.

A.3.1.5 Site Considerations

Site selection was a problem of considerable magnitude. Besides being spaced at 0.425° from each other, the receivers all had to be situated in a horizontal plane. Since the receiver line had to be manned, the receivers could be situated neither closer than 7 miles to ground zero nor north of the access road to the airstrip, in accordance with AEC regulations. Furthermore, due to the blast

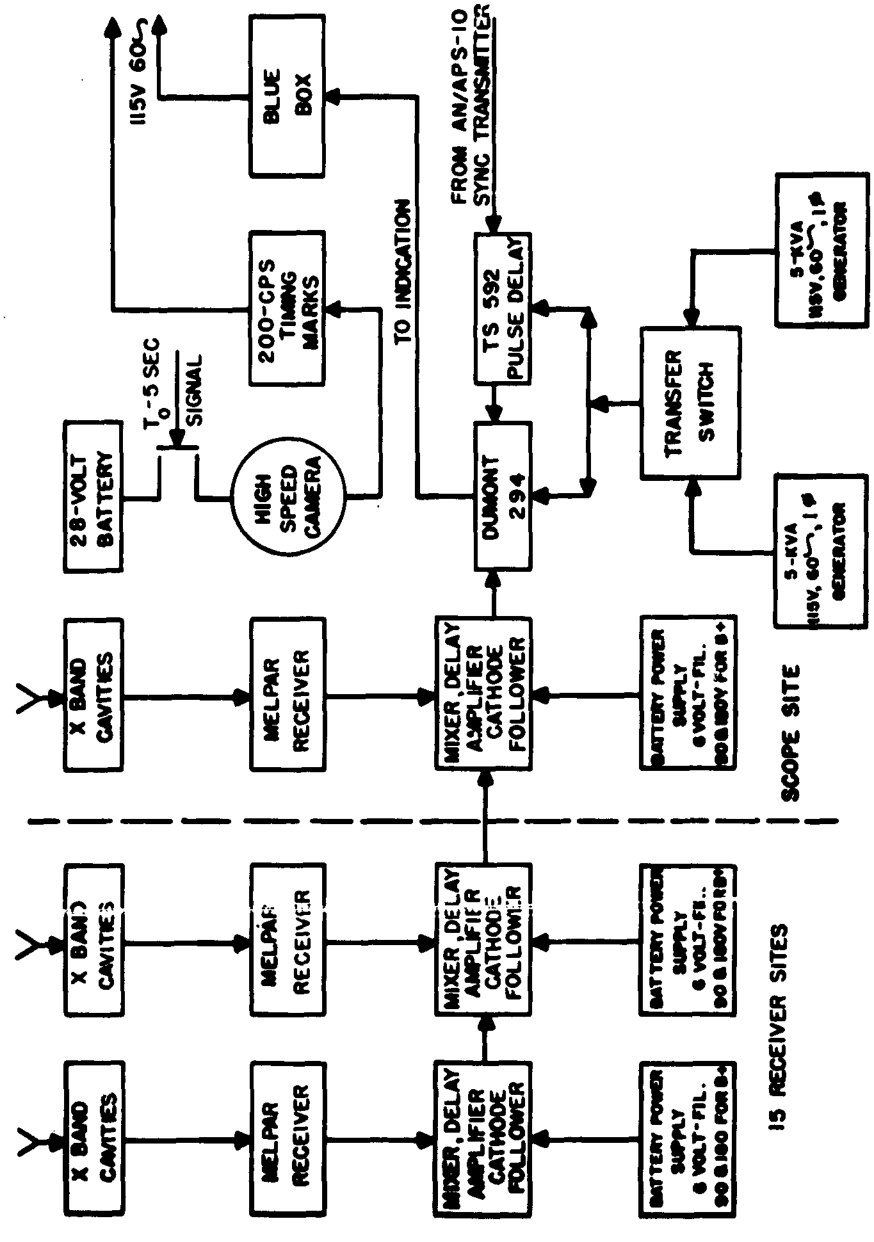

Fig. A.3 Block Diagram of Receiver Line and Oscilloscope Site

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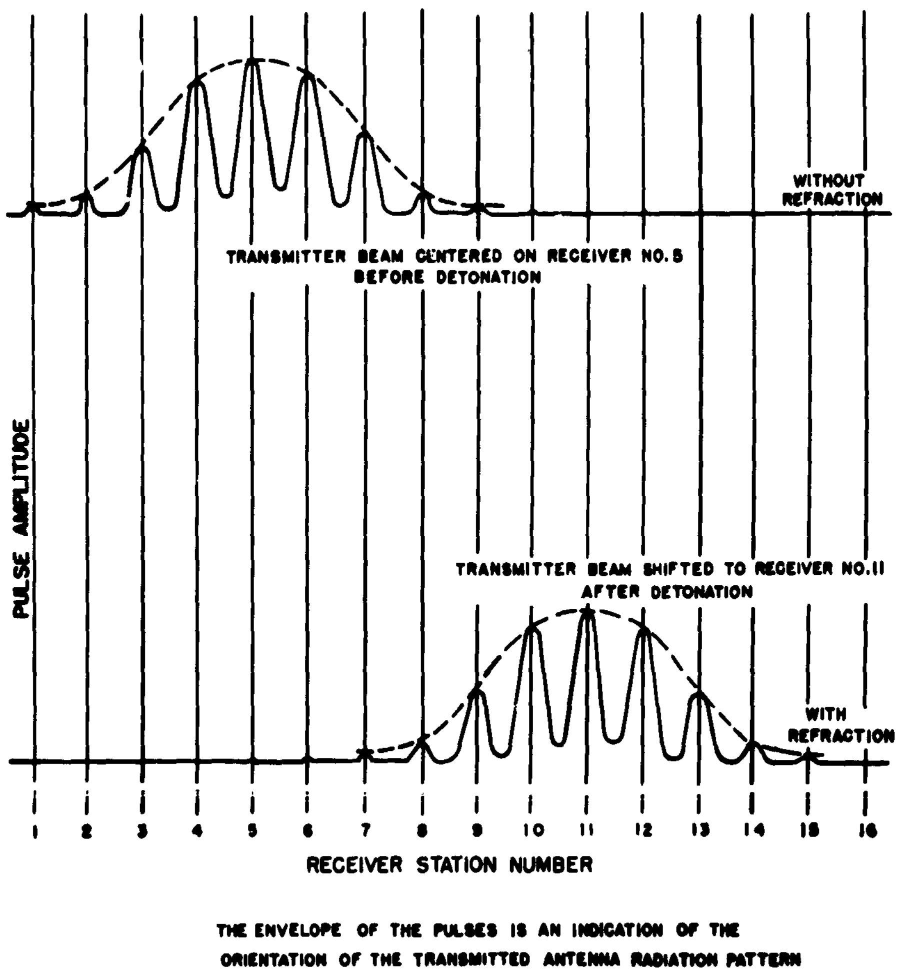

Fig. A.4 Typical Oscilloscope Trace Showing Amplitude of Pulses Arriving at Receiver Line

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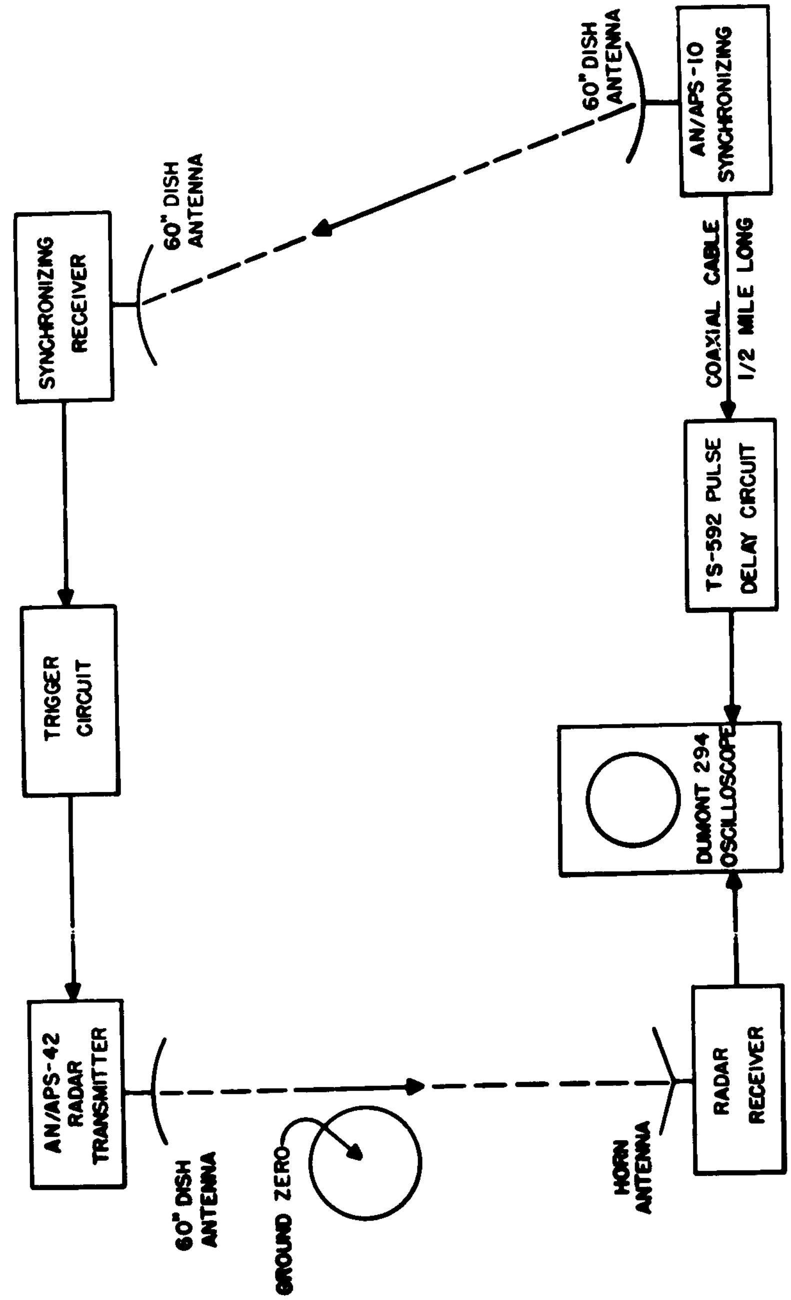

Fig. A.5 Block Diagram Showing Use of Synchronizing Transmitter and Receiver

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pressure, the truck housing the synchronizing receiver and the AN/APS-42 radar transmitter could not be located closer than 6 miles to the burst lest the 60-in. parabilic reflector antennas get damaged by the blast.

In spite of the fact that the truck-mounted AN/APS-42 transmitter was maintained a minimum of 6 miles from ground zero, braces were installed on the side of the van opposite to the burst to prevent the capsizing of the truck by the blast pressure of the shock wave.

A.3.1.6 Mobility of Equipment

Because line of sight through the burst had to be maintained between the AN/APS-42 transmitter and the receiver line, it was necessary to relocate the test sites for each shot. For this reason, it was imperative that the equipment be readily transportable from place to place.

The AN/APS-42 transmitter and the synchronizing receiver were both mounted in the same truck, while the two generators supplying power to these were trailer mounted. Therefore, all equipment at this site was easily moved.

The equipment for each receiver station, including the battery power supply, was installed in a wooden instrument shelter which was easily carried about from one site to another by loading it with an A-frame on a 2-1/2 ton truck.

The equipment for the oscilloscope site and synchronizing transmitter site, however, was installed in light frame shelters with 8 x 12-ft. floor size and mounted on wooden skids so that they could be dragged about behind a 2-1/2 ton truck.

A.3.1.7 Cable Relocation for Each Shot

Both the coaxial cable and the field telephone lines that were strung out between receivers had to be picked up and relaid for every shot. Since over 2 miles of each were used, this was a problem of considerable importance.

A.3.2 Time History Experiment

A.3.2.1 Fundamental Layout

The time history (TH) experiment, the aim of which was to study the direct radar returns from a burst, was much less involved than the refraction experiment just described. The instrumentation for this phase consisted of a standard radar set AN/APS-42 and a DuMont type 294 oscilloscope, on which the returns were displayed and photographed, pulse for pulse, with a high-speed camera. The radar antenna, which was the standard antenna ordinarily used with the AN/APS-42, was centered on the expected burst position and locked into place. The antenna has a beam width of 5-1/2°. This site was located west of the control point and from 8 to 14-1/2 miles from the various ground zero locations.

A.3.2.2 Antenna Mount

Because of the distance from the TH site radar system to ground zero, it was important that the antenna not move about, once having been locked into position on target. To minimize movement by the wind, the antenna was mounted on a rigid frame firmly imbedded in the ground, and was separated from the instrument shack itself since the shack would shake appreciably in the wind.

A.3.2.3 Modifications to Radar Set AN/APS-42

The radar set was modified to the extent that the video signal was no longer cut off by a limiter stage so that the pulses presented on the oscilloscope were proportional to the signal intensity received at the radar antenna. A delay circuit was introduced between the radar set trigger signal and the sweep circuit of the oscilloscope. Thus, any portion of the sweep of particular interest could be expanded on the oscilloscope and studied in detail.

Radar set AN/APS-42 operated on an X-band frequency of 9375 megacycles and had a pulse repetition frequency of 780 pulses per second. The voltage supply requirements were 28 volts d-c and 115 volts, 400 cycles a-c. (See Fig. A.6.)

A.3.3 Auxiliary Refraction Experiment

A.3.3.1 General

It was learned that a unit from the Naval Electronics Laboratory (NEL) would be observing the detonation with a radar system which had a very high rate of scan (20 scans/sec). Arrangements were made to have this unit arrive at NPG one week earlier than originally planned, to participate in one of the shots for the purpose of investigating radar refraction phenomenon. This experiment had two objectives: to obtain additional data concerning the refraction by the fireball of electromagnetic radiation in the region of radar frequencies, and to obtain some idea of the feasibility of using a fast scan radar system and corner reflectors to observe this refraction phenomenon.

A.3.3.2 Fundamental Layout

The instrumentation for this experiment consisted of the NEL fast scan radar system and five radar corner reflectors. The data were recorded on film by photographing both the PPI scope and the magnified B-scope sector presentations. One photograph was taken for each scan of the antenna.

A.3.3.3 Orientation Consideration

The radar set was placed at a convenient site to command a good view of the shot tower. The five corner reflectors were so positioned

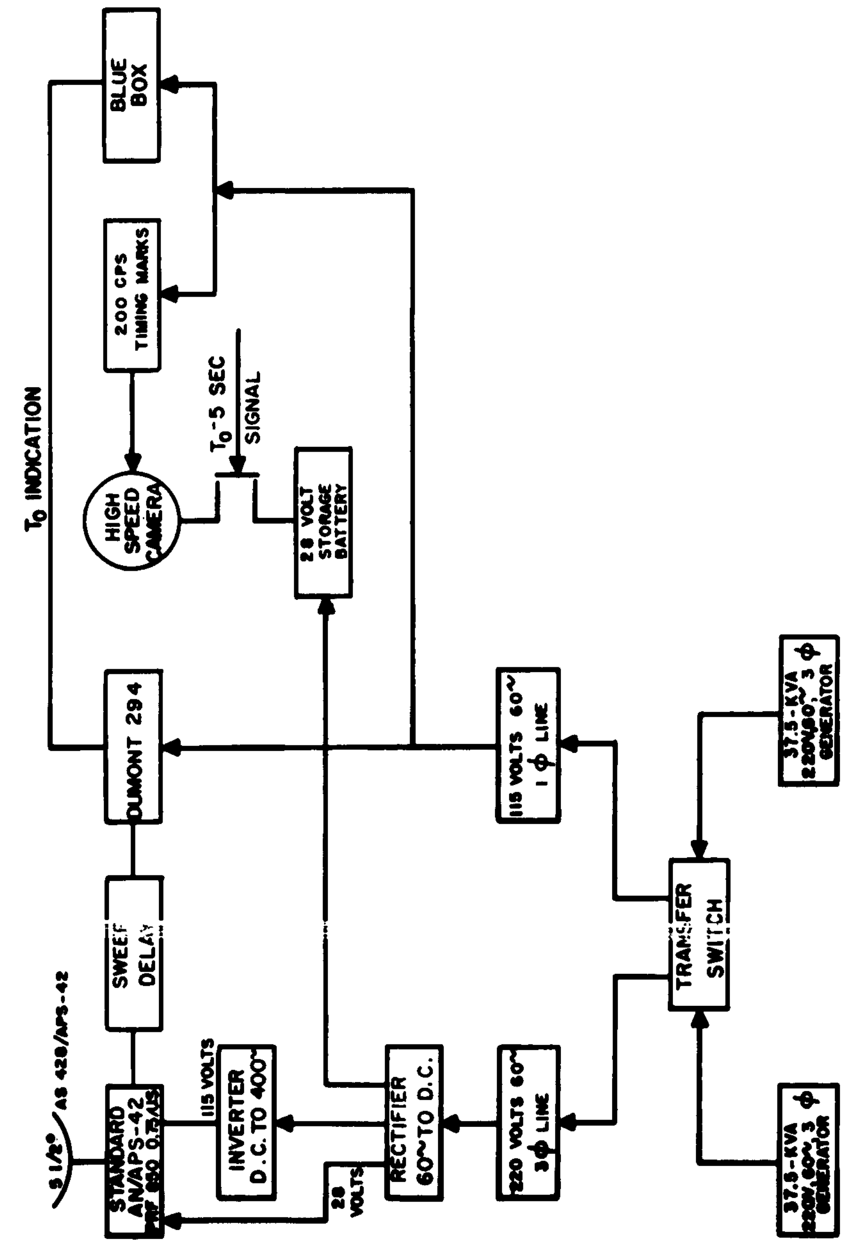

Fig. A.6 Block Diagram of Time History Experiment Apparatus

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that the first was practically on the line of sight through the shot tower and the radar set. The four remaining reflectors were in the same horizontal plane as the first and spaced at 1/2° intervals from each other. (See Fig. A.7.)

The reflectors at a greater angle from the line of sight through the shot tower were placed closer in range. Since the NEL radar system has an azimuthal resolution of approximately 5°, this variation in range made it possible to resolve the returns from the reflectors spaced at 1/2° intervals.

A.3.3.4 Phenomenon Observed

By observing the position of the radar reflectors indicated on the PPI scope, it was possible to determine whether or not any refraction of the electromagnetic radiation took place. (See Fig. A.8)

Previous to the detonation the radar beam proceeds along the path C and the reflector is indicated on the PPI presentation at its actual position A. After T_0, assuming that the beam is bent in toward the burst, the radar beam travels along path D. Consequently, to the radar system, the reflector has shifted to position B, changing not only the azimuth but also the range since the path length for D is longer than that for C. This shift of the position of the reflector is a continuous process and is not a sudden transition from A to B. Furthermore, the change in range for an appreciable deviation of azimuth is negligibly small. For this reason, it is better to measure the apparent lateral shift of the reflectors.

A.4 OPERATIONS

A.4.1 General

As the test operation progressed, it was found necessary to make minor alterations in the original experimental layout and to make minor modifications in the electronic equipment. These alterations and modifications are not considered of sufficient importance to include as part of this report. Details may be seen in Vitro report [illegible].

The instrumentation employed was set up and calibrated prior to each shot. The calibration procedures are not considered unique and therefore, are not made a part of this appendix. Considerable difficulty was encountered in properly aligning the 60 in. parabolic radar antennas, however, considering the narrow 1.7° antenna beam width, this difficulty was to be expected.

After each shot, the exposed film was sent to the project officer at Kirtland Air Force Base via the Indian Springs Air Force Base - Kirtland Air Force Base Shuttle aircraft. The film was processed by "West Lab" of Sandia Corporation. The project officer made a cursory examination of the processed film and reported any discrepencies to the NPG personnel prior to the next shot.

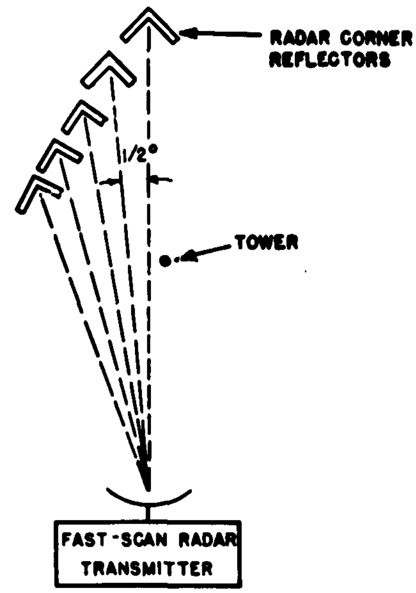

Fig. A.7 Orientation of Reflectors, Tower, and Radar Transmitter for Refraction Experiment Using Fast-Scan Radar

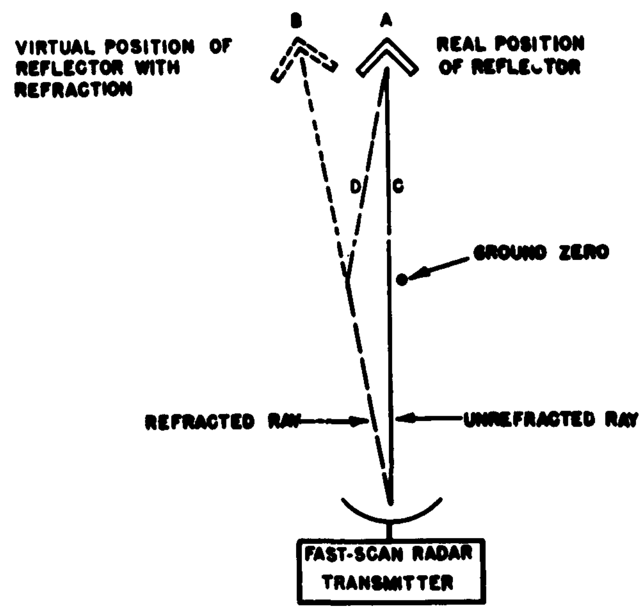

Fig. A.8 Diagram Showing Shift of Position of Reflector Due to Refraction of Radar Beam as Seen on PPI Indicator of Fast-Scan Radar System

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A.5 RESULTS

A.5.1 General

The data for the various experiments were recorded on film. Measurements were made later from the film with the use of a film reader which magnified the image 18 times.

All available data were analyzed and graphs were plotted. It was considered unnecessary to include the graphs in this appendix.

A.5.2 Refraction Experiment

For this experiment the oscilloscope display of the signals from the individual receivers was photographed trace by trace. Each trace showed a pulse for each receiver within the transmitted radiation pattern.

The amplitude of each pulse on a recorded trace was measured in centimeters as presented on a film reader with a magnification of 18. These amplitudes were graphed in two fashions: a plot was made of the pulse amplitude for each receiver as a function of time (frame number); and the pulse amplitude was plotted as a function of azimuth (receiver station number) for several specific time instants.

Since the base line of the trace was quite distinct, there was no difficulty in choosing a reference line. From this reference line the maximum value of each pulse was measured and recorded. The cameras were started 5 sec before T_0 and operated for about 30 sec. Consequently, much more data were available for reduction than was significant to the experiment. Hence, the data reduction was begun at an arbitrary point prior to T_0, depending upon the activity of the pulses, and was continued for as long a period after T_0 as required to include all the pertinent activity. Physical properties of the burst were taken into account in determining when the pertinent activity had ended. Not every trace was measured during the period of pertinent return. For example, when the amplitude of the return from a given receiver varied slowly, measurements were not made as frequently as in the cases when the amplitudes changed rapidly with time. Consequently, during periods of quiescence several frames of data were omitted. The frequency of measurements of the pulse heights is variable depending upon the activity of the radar returns.

A.5.2.1 Shot 1, 17 March 1953

No data obtained because of equipment failure.

A.5.2.2 Shot 2, 24 March 1953

The graphs of pulse amplitude versus time (frame number) show a period of relatively little change for approximately 0.1 sec after T_0, then the signal strength at each of the receivers fluctuated widely for a period of about 0.4 sec. The receivers closer to ground zero realized this fluctuation first, while those further away received

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it progressively later. This oscillation of signal strength was much greater for those receivers nearer the burst than for those farther away. The frequency of this signal strength oscillation was of the order of 200 cps. The receivers closer to ground zero were blanked out and received no signal when they apparently were in the cloud shadow. This blanking began at the station nearest ground zero, moved out to include several stations, then started to move back in again when the measurements ended.

A.5.2.3 Shot 3, 31 March 1953

On this shot the yield was unexpectedly low and the blue box did not trip. As a result, there is no T_0 indication and the data are too ambiguous to be of any value, since T_0 cannot be determined from the return characteristics.

A.5.2.4 Shot 4, 6 April 1953

This shot was an air burst and the refraction experiment was not performed.

A.5.2.5 Shot 5, 18 April 1953

Because of the topography of the Nevada Proving Grounds it was not possible to perform the refraction experiment. Instead a control experiment was conducted in which no radar transmitter was used. The data are not tabulated but the film shows no change either at T_0 or later. This indicates that the effects observed in the other experiments were not due to electromagnetic radiation emitted by the burst or to any other effect of the burst on the experimental equipment.

A.5.2.6 Shot 6, 11 April 1953

Again, a marked oscillation in signal strength occurred which seemed to move out from ground zero with time and decreased in intensity as it moved out. The receivers with the higher numbers were closer to ground zero while those with lower numbers were further away. Receiver Nos. 8, 7, and 6 received the signal oscillation immediately at T_0 with No. 8 settling down first, then No. 7, and finally No. 6. Receiver No. 5 apparently saturated and produced no useful signal but No. 4 and No. 3 both later experienced the large amplitude oscillations which apparently had a frequency of about 90 to 100 cps. Receiver No. 9, nearest to ground zero of all receivers within the transmitter antenna radiation field, was blanked out immediately at T_0 with No. 8 and No. 7 becoming blanked successively. The signals returned to those receivers in the order 7, 8, and 9.

After the large amplitude oscillations, which lasted about 0.1 sec, the receivers went through a stage of a very slowly oscillating change in signal strength. The amplitude of these oscillations was fairly small compared to the wild oscillations experienced right after T_0.

The plots of signal strength versus azimuth (receiver station number) showed no change in the pattern with time if the large amplitude oscillations and the blanking out of receivers No. 7, 8, and 9 were not considered.

About 8 sec after T_0 a second distrubance caused an oscillation in signal strength at the receivers. This distrubance affected the outer receivers first, then moved toward ground zero. This oscillation was of much smaller amplitude than the first and its frequency was of the order of 0.1 to 0.5 cps.

A.5.2.7 Shot 7, 25 April 1953

A sharp break occurred at T_0 with the signal from all receivers dropping to the noise level for two frames. After two frames (0.0025 sec) all the receivers except No. 10, which was most directly in line with ground zero, recovered somewhat and started a small and slow oscillation. Receiver No. 10 did not recover throughout the data recording period of 10 sec. Meanwhile, the wild oscillation observed on the other tests occurred first on No. 9, then in succession to receiver No. 1. The frequency of the oscillation was of the order of 100 cps and lasted longer at those receiver stations further from ground zero.

A short time after T_0 (0.03 sec), receiver No. 9 blanked out followed successively by receivers No. 8 through No. 3. The signals then reappeared on all receivers in the reverse order.

About 6 sec after T_0, the second series of signal intensity oscillations appeared, affecting successively receivers No. 1, to No. 9. This oscillation was of the order of 10 cps and the disturbance apparently moved toward ground zero at a much slower rate than the first oscillations moved outward.

A.5.2.8 Shot 8, 19 May 1953

In general the same features are apparent as for the previous cases. The portion of the beam nearest ground zero was blanked out and reappeared later. A wild oscillation in the signal strength moved outward from ground zero at first and then back again at a much later time. The frequency of the first oscillation was of the order of 250 cps while that of the second oscillation was 0.2 cps. For this case the antenna was centered on receiver No. 4 and the pulse amplitude from receiver No. 4 prior to T_0 was the maximum of all the receivers.

A.5.2.9 Shot 9, 8 May 1953

This was an air burst and the refraction experiment was not performed.

A.5.2.10 Shot 10, 25 May 1953

This was an air burst and the refraction experiment was not performed.

A.5.2.11 Shot 11, 4 June 1953

This was an air burst and the refraction experiment was not performed.

A.5.3 Time History Experiment

The data for this experiment were also recorded on film but, unlike the refraction experiment, both high-speed and low-speed cameras were used to photograph the oscilloscope trace. As before, the high-speed camera photographed each oscilloscope trace but the low-speed camera superimposed two or three traces on each picture frame. Measurements were made on both the low-speed and high-speed films using the same techniques.

In the first few shots the gain of the radar receiver was set so low that no ground clutter appeared on the trace. As a result, the base line on these films was sharp and it was not difficult to establish a reference line for the determination of pulse amplitudes.

In the later shots the gain was set relatively high and the ground return made establishment of a suitable base line more difficult. Because the film was transported through the high-speed camera with a continuous rather than an intermittent motion, the trace sloped downward with a slope proportional to the oscilloscope trace sweep rate. Furthermore, the mountains in the background produced more ground return than did the intervening valley, causing an apparent slope to the trace. Hence, the selection of a base line was largely a matter of judgment. This factor, although important, was not critical if choice of base line was consistent from trace to trace for a given portion of the trace since the variation of the pulse amplitude rather than the absolute amplitude was of concern.

The frequency at which measurements were taken was determined in much the same fashion as in the refraction experiment. When the change in amplitude of a given pulse was small from trace to trace, measurements were not made and those frames were omitted.

A.5.3.1 Shot 1, 17 March 1953

Experiment not performed because of the lack of timing signals.

A.5.3.2 Shot 2, 24 March 1953

The data show a sharp drop in signal amplitude at T_0 followed by a mild oscillation lasting for about 1/4 sec. At this point the signal amplitude started oscillating wildly with a frequency of about 130 cps. The wild oscillation lasted about 0.2 sec and settled down to a mild oscillation lasting for about 1/2 sec. The receiver gain was set so low for this test that prior to T_0 only a return from the tower was evident and no ground clutter appeared on the rest of the trace.

A.5.3.3 Shot 3, 31 March 1953

Due to the unexpectedly low yield the blue box did not trip and gave no T_0 indication. Since T_0 cannot be ascertained from the characteristics of the data, no conclusions can be drawn.

A.5.3.4 Shot 4, 6 April 1953

The film in the high speed camera broke on starting so that no data were taken on this shot.

A.5.3.5 Shot 5, 18 April 1953

The gain of the radar receiver was set so low for this shot that there was no ground clutter and only the pulse return from the tower was evident. At T_0 this pulse disappeared and the trace was flat throughout the rest of the film.

A.5.3.6 Shot 6, 11 April 1953

The gain of the radar receiver was set so low that only one pulse appeared on the trace. This pulse was so small that no change in its amplitude could be measured throughout the period near T_0 and later.

A.5.3.7 Shot 7, 25 April 1953

Because of difficulty in starting the cameras no data were recorded for this shot.

A.5.3.8 Dry Run, 4 May 1953

No observable change in the pulse amplitude was recorded on the film.

A.5.3.9 Shot 8, 19 May 1953

Data were not obtained with the low-speed camera because the camera clutch broke and the film did not run through.

The graph of the data obtained by the high speed camera, shows that the pulse amplitudes for ground zero and for the vicinity near ground zero were quite similar in behavior. At T_0 there was a sharp drop, followed by a small, slow oscillation which lasted for about 1/2 sec for both curves. At this point the returns from ground zero began a rapid, large-amplitude oscillation which continued for about 1/2 sec with a frequency of approximately 85 cps. At a later time the returns from the vicinity near ground zero began the rapid large amplitude oscillations which lasted for 0.3 sec and had a frequency of about 36 cps.

A.5.3.10 Shot 9, 8 May 1953

For this shot the gain of the radar receiver was set high so that there were good ground returns. This, plus the fact that this was an air burst, made the pulse returns in and about ground zero more difficult to distinguish than in the previous cases. The location of the burst was caluclated and the region was studied which showed fluctuations. At T_0 there was a small, sharp rise in signal amplitude followed by a slow, small oscillation which lasted about 1-1/2 sec. After this the wild oscillation in signal strength, observed in the previous tests, started up and lasted for 3 sec.

A.5.3.11 Shot 10, 25 May 1953

The T_0 light was so faint that it was difficult to determine when it went out. Consequently, there was no indication of T_0 on the data. The curves show the presence of the high-amplitude oscillations but it cannot be determined how long after T_0 these occurred. The frequency of the oscillation was of the order of 100 cps.

A.5.3.12 Shot 11, 4 June 1953

The T_0 light was too faint to photograph well and it cannot be determined precisely where the light goes out. The data show no marked features, and the high-amplitude oscillations apparent in the other cases were not evidenced here.

A.5.4 Auxiliary Refraction Experiment

The Naval Electronics Laboratory system had no T_0 indicator but at approximately the expected time a bright flash appeared on one frame of the PPI presentation film. This apparently was caused by light leaking into the camera and scope and therefore indicated T_0. Immediately after this bright flash, in the vicinity of ground zero, an expanding distrubance was observed which traveled outwardly very rapidly. The effect of this disturbance was to cause the ground returns to scintillate. This phenomenon was quite suggestive of the wild oscillations observed in signal amplitude on other occasions.

Looking further out in range to the expected position of the reflectors did not provide additional data since the returns from the reflectors were never absolutely defined. At the range used, the azimuthal resolution of the radar system prevented detection of any small shift in angle.

The B-scope presentation showed no T_0 indication and T_0 could not be determined with any accuracy. Again the reflector returns were not identified. At some time after T_0 the returns in line with the burst were blanked out as though they were in the shadow but no conclusive shift could be observed before this blanking out of signal.

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A.6 DISCUSSION

A.6.1 General

The electromagnetic refraction experiment was conducted on six of the seven tower shots. For the remaining shot it was impossible to find satisfactory site location, hence participation in that shot was omitted. Data were obtained in five of the six shots.

The time history experiment, however, was performed on all 11 shots and data were obtained on eight of the 11 shots.

A.6.2 Refraction Experiment

The phenomena associated with an atomic burst have a marked effect on the transmission of microwaves in the vicinity of the burst. The effect, however, is far more complicated than simple refraction, furthermore, it is impossible to separate the refraction effects from the other effects with the present data. It is possible, however, to draw some conclusions about the refraction.

The refraction of the radar beam must be small. If it were as large as had been anticipated, its effect could not have been masked by the other effects. It must be noted that in no case was a signal detected after T_0 at a receiver which had no signal before T_0.

The more pronounced effects show some interesting features and add to the fund of knowledge concerning phenomena associated with an atomic burst. The most striking of these features is the rapid fluctuations of the signal strength received at the various receivers. Significantly, these fluctuations did not usually begin at T_0 but started at various times after the burst. The further a receiver was from the continuation of the line connecting the transmitter to the burst, the longer was the elapsed time after T_0 before a fluctuation was observed in the signal received. The fluctuations lasted for about 1/4 sec.

After a much longer interval (about 10 sec later) the signals began to fluctuate again. At this latter time, however, the fluctuation occurred earlier in the outer receivers.

The amplitude of the received signal during the period of fluctuation goes through a series of irregularly spaced and irregularly shaped maxima and minima. The time between the maxima is irregular but corresponds roughly to a frequency of 100 cps for the early period of fluctuation and of about 1/2 cps for the latter period.

It was impossible to associate the fluctuations of the signal received in one receiver with that received in another. The variations in any one receiver appear to be independent of those in any other except for the time at which they start.

The observed phenomena can be depicted as the result of a disturbance moving initially away from the burst and then moving back toward it. The effect of this disturbance may be thought to cause random changes in amplitude of the radar signal moving through it. The effects produced decrease with time after T_0.

Before attempting to explain these results, it is necessary to indicate one additional fact. The antenna radiation pattern, determined by plotting the amplitude of the signals received at the various receivers versus the angular spread of the receivers, was quite different from the actual free space antenna pattern.

A possible reason for this is that the signal that reaches the receiver is actually the sum of signals that have traveled different paths. One path is the direct path from the transmitter. Other paths would involve reflection by the ground. Since the actual paths involve nearly a million wave lengths, it is quite certain that the differences in path length would be many wave lengths. Thus the phase difference between the signal arriving via different paths would be essentially random and the amplitude resulting from their addition might vary from nearly zero to larger than that of any individual signal. Thus, the amplitude of signal received at any receiver would depend not only upon the angular spread between the line from the transmitter to that receiver and the direction of maximum power output of the transmitter, but also upon the nature of the interferences caused by the multipath transmission. This would explain the reason why regular patterns of the form of Fig. A.4 were not observed. It is important to note, however, that the receivers outside of the beam of the antenna would under no circumstance receive an observable signal without the presence of refraction.

The fluctuations of the received signals that were described above can be explained on the basis of this multipath transmission. The atomic explosion provides a region in space (the fireball) with optical properties considerably different from those of normal air. The edge of the region, moreover, is probably not sharp. The optical properties change gradually from those of normal air.

After T_0, this region expands. When the region moves in between the transmitter and a given receiver, the direct optical path to that receiver is effectively changed. The paths via ground reflections may also be changed but probably not so much. The result is a phase change between the various paths and therefore a change in the resultant amplitude. As more of the disturbed region moves between the transmitter and the receiver the effective length of the direct path is further changed. Since the distance involved is so large compared to a wave length, it is reasonable to expect the optical path to change by many wave lengths. The resultant amplitude will then show many maxima and minima corresponding to instants of time when the path difference was an even or odd multiple of the wave length.

The second series of oscillations occurs as the fireball rises or cools off. The effective edge of the sphere would then be in line with the outer receivers first.

Another possible explanation of the oscillations is that they are due to oscillations of the fireball sphere. These oscillations would cause a regular variation of the effective path difference between direct and reflected waves. This would result in the observed oscillation of the amplitude. Calculations based on a simplified model of the fireball indicate that such a sphere should have fundamental

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modes of vibration of the same order of magnitude as those observed.

A second major effect of the burst on radar transmission was noticed at times shortly after the first period of wild fluctuations. The signal arriving at the inner receivers - those nearest the transmitter to burst line - diminished to the noise level. The signal at the innermost receiver disappeared first. At times considerably later, these signals reappeared and in the reverse order to that in which they disappeared.

This phenomena is similar to that observed by airborne radar and is called the fireball cloud shadow. The most logical explanation is that the radar energy is absorbed by the ions formed in the fireball cloud. Therefore, the region behind the cloud, that is, in its shadow, is never reached by the radar transmission.

A.6.3 Time History Experiment

The time history experiment showed results similar to those of the refraction experiment. The occurrence of the burst had a major effect on the transmission of microwaves in the vicinity of the burst. These effects can be explained on the same basis as those observed during the refraction experiment.

There was no observable reflection from the burst itself. This indicates that the "bright spot return" observed with airborne radar did not emanate from the fireball. The reason why the fireball does not serve as a good reflector is probably the gradual change in ionization around the fireball. The change is so gradual that there is no appreciable shift in optical properties of the air in one wave length. Under such conditions reflections cannot be expected.

Similarly, the other effects detected by the use of airborne radar were not observed. Neither the "annular return," that is, a region expanding at the rate of motion of shock wave intersection of the ground and showing increased reflection, nor the cloud shadow, a region of no radar reflection, was detected. The failure to detect these phenomena may have been due to the wide antenna beam width and long pulse duration used. This method of operation resulted in the signal received at the radar set at any instant being the integrated result of reflection from a rather large area of land. The portion of the beam blanked out by the cloud shadow was actually a relatively small fraction of the total beam, and therefore this effect could not be observed.

The effects that were observed were the same type of irregular random fluctuation of the amplitude of the reflected signals as was observed in the refraction experiments. It is felt that these fluctuations were caused by the same phenomena. The signal arriving at the radar antenna at any instant was the result of reflections that arrived from many different objects, and that traveled many different paths. The burst caused changes in the effective length of some of the paths and thus changed the interference pattern at the antenna.

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In most cases, the period of large fluctuations began considerably after T_0. This would indicate that the observed reflections were from objects at some distance from ground zero, that is, at the outer edges of the beam. This is quite reasonable since reflections from the center of the beam would probably have been obliterated by the cloud shadow. Furthermore any buildings around ground zero would have been destroyed.

A.6.4 Auxiliary Refraction Experiment

Observation of the reflectors by rapid scan radar did not reveal refraction. There was no observable shift of those returns which were tentatively identified as the reflectors. This may have been due to the fact that the shift in range for any reasonable amount of refraction would be too small to be detected. Similarly an angular shift might not be detectable since the angular resolution of the instrument is quite poor, the antenna beam width being 5°.

Observation of the region around ground zero with this equipment showed the same effects observed in the two other experiments. Immediately after T_0 the returns in the region around ground zero were observed to scintillate. On the PPI presentation the expansion of the region of signal fluctuations could be observed. The cause for this effect is presumed to be the same as that discussed above.

A.7 CONCLUSIONS

A.7.1 Refraction Experiment

The refraction of the radar beam was too small to be observed in the presence of other large scale effects.

The most pronounced effect observed was the large fluctuations in the amplitude of the signals received. This phenomenon is tentatively interpreted as being due to interference effects between signals that had traveled different paths.

The signals received at those stations nearest the transmitter-to-burst line disappeared shortly after T_0. This effect was assumed to be due to the absorption of the radar beam by the fireball cloud.

A.7.2 Time History Experiment

No reflection of the radar beam by the fireball was observed.

The phenomena observed by airborne radar, the annular return and the cloud shadow, were not detected in these experiments.

Fluctuations similar to those observed in the refraction experiment were observed. The cause of these fluctuations is assumed to be the same as that in the refraction experiment.

A.7.3 Auxiliary Refraction Experiment

The refraction of the radar beam was too small to be observed with the resolution available.

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An expanding annular ring was observed in this experiment. In this ring the ground painting appeared to scintillate. These fluctuations in signal strength of the radar returns were similar to the oscillations observed in the refraction and time history experiment.

A.8 RECOMMENDATIONS

A.8.1 General

A more quantitative evaluation of the refraction phenomenon, a detailed search for both the annular return and cloud shadow, or a more precise explanation of the cause of the large fluctuations in signal strength would require further experimentation.

A.8.2 Refraction

If further investigations are desired, several methods of instrumentation are feasible for the performance of the refraction experiment. They are presented here in order of preference.

A.8.2.1 Fire Control Radar System

The most desirable method is to observe the returns from a beacon transmitter with two narrow beam antennas offset by a small angle. Possibly a modification of an existing fire control radar system would be adequate to perform the experiment. The use of two separate antennas is necessitated by the rapidly fluctuating signal strength observed during the present test. The returns from both directions have to be compared simultaneously. A conical scan or a lobe switching system would not be suitable since the fluctuations would produce false "bending" information. The use of the monopulse system is ideal, since with this system the returns from both directions are observed continuously and compared simultaneously.

By using a transponder beacon all ground returns would be eliminated and the use of narrow antenna beam width increases the resolution possible.

A.8.2.2 Narrow Beam Antenna

A second method for the refraction experiment consists of the same system as used during this test but with the use of a much smaller antenna beam width. The use of a K-band radar system with a very large parabolic reflector would permit closer spacing of the receiver stations. Furthermore, with the narrow beam width, it is not necessary to observe the patterns to determine the central ray. All that has to be recorded is whether or not a particular receiver station detected a signal.

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A.8.2.3 Fast Scan Radar

A third method is to use a fast scan radar system observing the returns on a PPI scope from either reflectors or beacons. The refraction can then be determined by measuring the azimuthal shift of the beacon or reflector returns.

This method has the advantage of providing refraction data as a function of azimuth. Several reflectors can be set up to determine the refraction for electromagnetic range passing at various distances from the burst center. However, this system has the disadvantage of a wide beam width which results in poor resolution.

A.8.3 Annular Return and Cloud Shadow

Should it be necessary to make a more detailed investigation into the annular return and the cloud shadow, the use of a fast scan radar system with good angular resolution is desirable. Observations should be made on a PPI scope and the gain setting of the radar set should be high enough to observe the cloud shadow and get good ground painting in the vicinity of the burst. It would be desirable to investigate the results at two frequencies, X- and K-band, by means of two radar sets placed side by side.

A.8.4 Signal Amplitude Fluctuations

During future tests, should it be desirable to investigate signal amplitude fluctuations experienced during this test, an experimental setup similar to that used during this test is recommended, except that a different arrangement of receivers should be used.

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